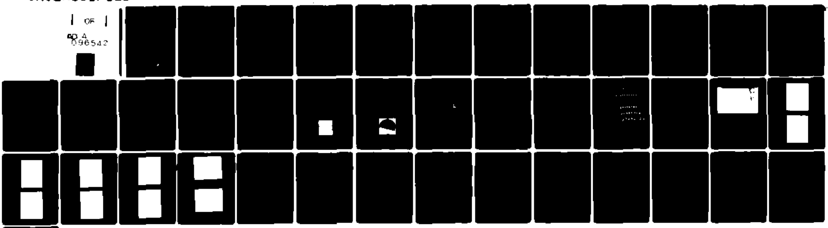
AD-A096 542 AERONAUTICAL RESEARCH LABS MELBOURNE (AUSTRALIA) F/G 9/2
APPLICATION OF COMPUTER COLOUR RASTER DISPLAYS IN THE COCKPIT I--ETC(U)
MAR 80 H A THELANDER
UNCLASSIFIED ARL/SYS-71 NL



1 OF 1
AD A
096542

END
DATE
FILMED
4-81
DTIC

ARL-SYS-NOTE-71 LEVEL (12) AR-001-798

AD-A096542

# DEPARTMENT OF DEFENCE

## DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

## AERONAUTICAL RESEARCH LABORATORIES

MELBOURNE, VICTORIA

SYSTEMS NOTE 71

# APPLICATION OF COMPUTER COLOUR RASTER DISPLAYS IN THE COCKPIT IN RESEARCH FLIGHT SIMULATION

by

H. A. THELANDER

Approved for Public Release.







COPY No 13

MARCH 1980

AR-001-798

DEPARTMENT OF DEFENCE
DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION
AERONAUTICAL RESEARCH LABORATORIES

SYSTEMS NOTE 71

AR/SYS-71

# APPLICATION OF COMPUTER COLOUR RASTER DISPLAYS IN THE COCKPIT IN RESEARCH FLIGHT SIMULATION.

by

H. A. THELANDER

Mar 80

12 | 14

*SUMMARY*

*This paper describes an experimental investigation of the factors influencing the use of computer driven colour raster displays for the provision of cockpit displays and instrumentation in manned flight simulation research. Cockpit information presentation requirements and raster display methods are discussed. The findings of the study are that the method has applicability to research simulation, with economic advantages over the conventional approach. The main factors affecting its use are quantified.*

POSTAL ADDRESS: Chief Superintendent, Aeronautical Research Laboratories,
Box 4331, P.O., Melbourne, Victoria, 3001, Australia.

# DOCUMENT CONTROL DATA SHEET

Security classification of this page: Unclassified

1. Document Numbers
   (a) AR Number:
   AR-001-798
   (b) Document Series and Number:
   Systems Note 71
   (c) Report Number:
   ARL-Sys-Note-71

2. Security Classification
   (a) Complete document:
   Unclassified
   (b) Title in isolation:
   Unclassified
   (c) Summary in isolation:
   Unclassified

3. Title: APPLICATION OF COMPUTER COLOUR RASTER DISPLAYS IN THE COCKPIT IN RESEARCH FLIGHT SIMULATION

4. Personal Author(s):
   H. A. Thelander

5. Document Date:
   March, 1980

6. Type of Report and Period Covered:

7. Corporate Author(s):
   Aeronautical Research Laboratories

8. Reference Numbers
   (a) Task:
   DST 78 145
   (b) Sponsoring Agency:

9. Cost Code:
   71 2260

10. Imprint
    Aeronautical Research Laboratories,
    Melbourne.

11. Computer Program(s)
    (Title(s) and language(s)):

12. Release Limitations (of the document)
    Approved for Public Release.

| 12-0. Overseas: | N.O. | | P.R. | 1 | A | | B | | C | | D | | E | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|

13. Announcement Limitations (of the information on this page):
    No Limitations.

14. Descriptors:
    Flight simulators
    Display devices
    Cockpits
    Sweep generators
    Computer graphics
    Aircraft instruments

15. Cosati Codes:
    0104

16.


*ABSTRACT*

*This paper describes an experimental investigation of the factors influencing the use of computer driven colour raster displays for the provision of cockpit displays and instrumentation in manned flight simulation research. Cockpit information presentation requirements and raster display methods are discussed. The findings of the study are that method has applicability to research simulation, with economic advantages over the conventional approach. The main factors affecting its use are quantified.*

CONTENTS

## 1. INTRODUCTION

A major cost and complexity component in a research-oriented *manned flight simulator* is presentation of information to the flight crew in the cockpit. The presentation must be adequate for the flying tasks posed in the various experiments, and must be flexible so that differing types and arrangements of the presentation can be investigated.

By contrast, in a specific-to-type training simulator the problem is confined to reproduction of the cockpit of the simulated aircraft with fidelity sufficient to permit transfer to flight operation of the skills acquired or enhanced in the simulator. This is a straightforward, albeit costly, engineering problem. Its solution is exemplified by the very accurate cockpit replications in the training simulators operated by air forces and airlines.

Computer driven graphic display presentation of cockpit information suggests itself as an alternative to the conventional technique of replicating the various instruments individually. This should reduce the complexity, and hence the cost, of the hardware, while offering flexibility through program rather than hardware change.

The aim of this study is to assess the factors affecting the use of digital computer driven raster graphics displays, using modified colour television receivers for output, to provide cockpit information presentation for research manned flight simulation applications.

## 2. COCKPIT DISPLAY CONTENT REQUIREMENTS

The cockpits of present day aircraft contain almost as many instruments as the panel space allows [1]. The essentially analogue technology basis of conventional aircraft instrumentation has forced the use of dedicated instruments: even parameters whose values need to be checked only once or twice during a flight, for example brake accumulator pressure, must be continuously displayed. Instruments have become smaller, and their functions have been combined where possible, but these processes are approaching their limits. At the same time problems have arisen from the difficulties experienced by aircrew in assimilating, and discriminating amongst, the sheer volume of data presented.

Display integration, providing adequate information for the conduct of the various phases of a flight or mission is clearly desirable. It has been made feasible by advances in digital electronics, and considerable progress has been sponsored particularly by the USAF [2] and USN [3]. The F-16 fighter of General Dynamics is a modern aircraft in which display integration has progressed considerably.

The following sections address conventional and integrated cockpit displays and the emerging specialized system and tactical control displays.

### 2.1 Conventional Instruments

Conventional aircraft instrument panel layout is today based on the "Basic T", Figure 1, which is itself an evolution of the "Basic Six" of the Royal Air Force in World War 2 [4, 5]. It is an ergonomically effective arrangement which eases the pilot's task of integrating the discrete displays.

Ranged about the centrally located Basic T are the multiplicity of other instruments, with an attempt at retaining the logic of the layout. Thus a Vertical Speed Indicator would in a standard layout be located below the Altimeter, and a Machmeter below, or to the left of, the Speed Indicator.

The form of the instruments has evolved in response to engineering and human factors requirements. Case designs have stabilized to standard forms [6] with the advantage of allowing exchange of equivalent types of different manufacture. Sizes range downwards from 127 mm (5 inches), governed by the relative importance of the information and available space.

Instrument faces are black, with white scales and pointers. Other colours are used for special reasons: pale blue-green to represent the sky on an attitude indicator, red or fluorescing orange on malfunction flags.

Most often the instruments are arranged with a centrally pivoted pointer (or, unfortunately, pointers) rotating in a circular scale. This has the benefit of readily allowing both rate and amount of change of the displayed parameter to be interpreted. Counter-pointer instruments can retain this quality and add accuracy of reading and reduced possibility of confusion.

Strip-type instruments are encountered, in both horizontal and vertical arrangement, and with either scales or pointers moving. Their case designs have not been standardized.

Standards for the principles of cockpit information presentation [7], governing such aspects as scale orientation and directions of motion, as well as details of numerals and letters [8] have been agreed. Much of this is owed to Working Party 10 of the Air Standardization Coordinating Committee: "Aircraft Instruments and Aircrew Stations" (e.g. [9]) through their publication of Air Standards.

There are many instruments in present day use. Two in particular were selected for representation by computer-generated raster display techniques. One is a two pointer plus counter speed indicator, Figure *2a*, the other an attitude indicator, Figure *3a*. Their replications by raster techniques are pictured in Figures *2b* and *3b* respectively.

### 2.2 Advanced Displays and Notes

Most integrated displays utilize digital computing techniques and cathode ray tube (CRT) display elements. Highly integrated multi-function instruments employing the conventional techniques are so costly, specialized and inflexible that their survival is problematic, though they have some proponents.

Hearne [10] reviews the principal characteristics of possible display elements and concludes that the CRT has sufficient advantages to retain almost exclusive pre-eminence in the cockpit, a conclusion still valid and likely to remain so into the 1980s. This is reflected by the fact that *integrated displays in or shortly scheduled for service are invariably* CRT-based.

Once freed from the constraints of the conventional instrument panel, designers have freedom to choose what is, and how it is, to be displayed. Whether formats will stabilize again, in Basic-T fashion, can only be conjectured, as the process is very much in its infancy. Two candidate cases are typical of the work being done and of the diversity of approaches.

NASA Langley Research Centre have implemented an advanced guidance and control system (AGCS), in which the main pilot's displays are the electronic attitute director indicator (EADI) and electronic horizontal situation indicator (EHSI). They have received study via simulation [11] and flight trials [12] in the role of approach and landing aids. The EADI, Figure 4, presents a "contact analogue"† of the aircraft attitude, in a format parallelling the conventional attitude director indicator, with radar height and flight-path angle acceleration added. The EHSI forms the human interface of a powerful navigation system.

The AGCS retains the layout of the Basic T (Figure 4 in reference [12] has captions for Altimeter and Airspeed Indicator exchanged). This will allow exploitation of existing aircrew flying skills with less re-training than would be needed for other arrangements.

The USAF, in the Digital Avionics Information System (DAIS) advanced development program [13, 18], and the USN, as sponsor of the F-18 [14] have pursued a more integrated approach. In DAIS, five CRT displays are proposed. These are the head up display (HUD), vertical and horizontal situation displays (VSD, HSD), and two multi-purpose displays (MPD). The HUD, outside the scope of this work, is the primary flight and weapon delivery display, providing the pilot with basic flight data attitute, altitude, speed – plus extra information relevant to the various phases of the mission. The VSD is a back-up for the HUD, and primary instrument in head-down flight. The MPDS are used mostly for textual data, and the HSD for a digitally generated map or to display sensor video. Exchange or sharing of functions between HSD and MPDs is possible. A typical DAIS arrangement is illustrated in Figure 5.

† That is, a picture analogous to that seen by the aircrew, looking out of their craft, in visual contact with the environment.

In so far as the integrated displays implemented or proposed up to the present are predominantly based on CRT display technology comparable with that employed by the techniques under investigation, it was considered that those techniques would be able to reproduce those displays. As the factors influencing their use are mostly the same as in the conventional type presentations, no specific integrated display formats were investigated.

### 2.3 System and Tactical Displays

These displays are used in monitoring and control of sensors and weapons and the complex tactical operations of modern military aircraft. Display integration, and the trend in the role of aircrew towards that of total systems management, is eroding their distinction from the traditional concept of cockpit instruments and displays.

Airborne anti-submarine warfare (ASW) is an application in which computer driven graphical displays, containing a mixture of data from various sensors and symbols, scales and the like [15], are used in management of the tactical situation. Figure 6 shows such a format: in existing equipments single-colour displays are used, but coloured displays, employing penetration phosphor CRTs, are available.

A system display encountered in a range of aircraft applications is the "tote", used mainly for tabulations of alphanumeric text. Typical capacities are ten to twenty lines of twenty to forty characters. A tote may have some graphical capacity; in ASW an application would be bathythermal data.

The Panavia Tornado multi-role combat aircraft employs displays known as "TV-Tab" (for TV plus Tabular), on which a variety of sensor video and computer generated data are displayed. Associated with the TV-Tab is a multi-function keyboard: a single row of large pushbuttons, immediately below the screen, whose functions are defined at a particular instant by a "menu" or legend on the screen.

Plates 10 and 11 show a tactical display format generated with the experimental equipment.

## 3. RASTER DISPLAY GENERATION METHODS

Two techniques for raster display generation can be identified: direct digital-to-video conversion and scan conversion of directed-beam images. The former is preferred in the research piloted flight simulation application, for reasons discussed in the descriptions of these techniques which follow.

### 3.1 Direct Video Generation

A video signal, carrying the intensity information for a raster-scanned picture, can be generated directly from data in a digital computer in a variety of ways. The precise method adopted will be determined by such factors as image content, motion, cost, and availability of technology.

Where the content of the image is continuously varying and moving, as for example in the external visual environment presentation for a flight simulator, and considerable cost can be entertained, it is possible to compute directly the intensity at each point in the image, and then output these data, in synchronism with the raster scan.

Where most of the content of the image is static, as for example in a representation of an instrument panel upon which only pointers and scales change, it can be an advantage to buffer the data so that only the changes need be computed, lowering the total data rate at the output of the digital computer. Buffer memories for this application have been feasible for many years, but their cost has until recently been quite high. Use of buffer memories is appropriate in the research flight simulator cockpit displays application.

Consider first a display in which information is presented in a single colour and intensity: extension to more colours and intensities follows naturally. The raster scan consists of a series of lines sweeping over the display surface. Clearly line width (or spacing) imposes a limit to the system's resolution. Each line is therefore subdivided into picture elements, or *pixels*, whose

dimension along the line approximates the line width or spacing. To each pixel there corresponds, in this simple system, one bit in the buffer memory, and the video signal is generated by reading out these bits in sequence and modulating the intensity according to whether the bit is a 1 or a 0.

A memory containing one bit per pixel is termed a memory *plane*, and a number of planes may be used together in parallel to provide that number of data bits per pixel. These can then produce different intensities or colours.

In the Australian standard 625-line television system, a full picture, or *frame* is drawn twenty-five times per second. Each consists of two *fields*, each a full-sized raster, whose lines are interlaced on the screen. The field frequency of 50 Hz reduces flicker of the picture (see section 5.2 below), while the lower frame frequency reduces the video bandwidth. The line frequency is 15,625 Hz, giving, after allowing for the blanking needed for field retraces, some 575 active lines, in which picture information occurs, per frame.

The number 512, an integral power of two, suggests itself as a likely number of lines per frame for a candidate display. (This represents a loss of about 11% of available lines). It appears convenient to take the same number of pixels per line; although this leads, in the standard, to pixels which are not square, and the consequences of this choice are discussed later. A frame then contains 262,144 pixels, and a single plane memory for it can be mapped into 16,384 (16 K) words of 16 bits (the word size of convenient mini- and micro-computers).

In generating the video signal, each bit of the memory is read twenty-five times per second, for an average data rate of 6.5536 Mbit $sec^{-1}$. Peak rates are higher: at 15,625 Hz a line period is 64 microseconds, of which 12 microseconds are reserved for line blanking, leaving 52 microseconds active time in which in this case 512 pixels are displayed, at a frequency very close to 10 MHz. In an appropriately organized memory consisting of 16-bit words, the peak requirement is therefore for one word to be read every 1.6 microseconds. If a secondary buffer is used for the 32 words corresponding to a single raster line then this may be reduced to an average rate of one word per 2.0 microseconds.

Logic speed requirements for such a system are quite modest, and the capacities involved are within reach of current MOS technology, so that a memory plane can be constructed on a single circuit card for a few hundred dollars (mid-1979).

A modular approach to the display system design offers ready extensibility, the number of available colours or intensities doubling with the addition of each further memory plane, whilst timing and control circuitry are unaffected.

The use of multiple modular planes offers a way of ameliorating a difficulty occurring in buffer memory display systems. This difficulty arises when it is desired to move an element in the image through the area occupied by another element, as happens, for example, when a pointer swings across the scale of a dial. The appearance of motion is achieved by erasing the moving element and re-drawing it in a new position. When the fixed elements occupy the same memory they too will be erased and must then be re-drawn. In a multiple-plane system the fixed information could simply be stored in a separate plane or planes.

### 3.2 Scan Conversion

A scan converter accepts an image encoded in one format and allows its readout in another [17]. Analogue scan converters typically record the image as a spatially varying charge pattern on the storage element of a storage cathode ray tube. The image is then read using a scanning beam. Many variants exist, providing persistent or decaying storage and destructive or non-destructive readout with simultaneous recording and replay for two-gun devices or timeshared recording and replay when only one gun is used.

Formats for image entry are flexible, for example raster or cursive (directed-beam) methods may be employed. Grey-scale capability is available, but at present coloured images require use of multiple converters and require fine adjustment for registration, increasing the cost prohibitively [20].

Digital scan converters may be implemented using a buffer memory in which the image information is stored. Data input becomes the limiting factor, for while it is relatively easy to design input logic to direct incoming raster data, digitized by a converter, of any given format to the correct sequence of addresses in the memory, this is not so for cursive data.

In conversion of data from one raster format to another, the digital scan converter, requiring no adjustment and able to store an image indefinitely without degradation, offers advantages. For conversion of radar and electro-optical sensor video in airborne systems, the digital converters are already replacing analogue converters. As its economics improve, the digital scan converter will make inroads in other applications. Scan conversion methods offer no advantages over the memory plane buffers and direct video generation approach of the previous section in the applications addressed by this study.

## 4. EXPERIMENTAL RASTER DISPLAYS

For the investigations reported here, a single plane memory was simulated with a PDP-11/20 minicomputer, and a controller was constructed. Colour television receivers were modified to accept signals from the controller. Representative formats were generated, displayed, and assessed subjectively and by measurement.

### 4.1 Video Generator Hardware

The PDP-11/20 is normally used in control of the Modular Analogue Computer. Among other things it has 24 K 16-bit words of 1.0 (approximately) microsecond cycle time core memory, two 1·25 M word removable disk cartridge drives, an interface with the ARL DECsystem-1070 central digital timesharing computer, and three DR11-B direct memory access (DMA) interfaces. One of the DR11-B interfaces operates with the Modular Analogue Computer Serial Digital Bus (DIGIBUS) subsystem, using the DIGIBUS controller. A video generator was built to plug in in place of the DIGIBUS controller, and to take synchronization signals from a locally built synchronization and grid pattern generator [21].

The video generator outputs data from 16 K words per frame by direct memory access, and thus allows the core memory of the PDP-11/20 to simulate a 512 × 512 bit memory plane. For experimental purposes the generator can, under program control, instead output two bits per pixel for the 256 pixels in the centre of each line (and nothing for the first and last 128 pixels). Independently, under program control, the pixel frequency may be set at 10 MHz or 15 MHz.

At the 10 MHz pixel frequency the 512 pixels occupy essentially the entire line, while in the vertical direction 512 of an available 575 lines are drawn. The standard television raster has a width to height ratio of 4 to 3, so that the pixels (at 10 MHz) have an aspect ratio of 4 to 3 × 512/575, or very close to 3 to 2. At the 15 MHz pixel rate the pixels become square, and the right hand third of each line is empty. Using the two bits per pixel feature, at 10 MHz the centre half and at 15 MHz the centre third of the picture is available. For experimental flexibility the two bits of pixel data are decoded into four signals, termed colour 0 (black), colour 1, colour 2 and colour 3. These are taken to a palette for manual control of the red, green and blue (RGB) content of each colour.

For simulation of moving pictures the disk storage subsystem of the PDP-11/20 was used. Data, computed off-line in the DECsystem-10, were written to the disks. Subsequently they were used to update the picture data in the memory.

### 4.2 Video Generator Software

Data for the experiments were prepared using the DECsystem-10, transferred to the PDP-11/20 using existing utility programs, and output through the video generator under control of a program in the PDP-11/20.

In the DECsystem-10 the data were mapped into an 8 K word array (two 16-bit PDP-11 words to the 36-bit DECsystem-10 word). On completion of image generation this was output in binary in a form suitable for the cross-loader program LODX11. The entire set of generation software could have been programmed in FORTRAN, however in the interests of speed of execution a number of primitive operations were coded in MACRO-10 assembler.

The basis of the software was a pair of primitives: one for entering and the other for deleting data for a single pixel addressed by its coordinates. This is in fact a sufficient set for all graphics operations. Primitives for drawing (and deleting) vectors, circles and area-filled triangles were

written, and from these yet higher level routines were derived. All were either written as or could at least be called as FORTRAN subprograms.

An interactive display program for the DECsystem-10 was written and used in the generation and, as needed, modification of numeric character (digits 0–9) fonts suitable for use in the experiments. At the outset, one numeric font had been drawn and coded by hand, but a clear requirement for a range of sizes emerged, and the manual approach was too time-consuming. Figure 7 illustrates the pixel patterns of the six fonts produced, and clearly shows the three-by-two proportion of the pixels.

These numeric fonts were used in the visibility measurements described below. To enable subjective assessment of display quality it was desirable to have a complete font of alphabetic characters for annotating instruments, for example. To avoid the time involved in generating a font, even using interactive computer graphics, the font data tables from the existing CISPAC software [22] were translated for use in the experiments. These characters are nine elements high by seven wide (for say an upper case "M") in a fifteen high by nine wide cell. They are used with the square resolution elements of the CIS display [22], and therefore when used in these experiments with the 10 MHz pixel rate appear laterally elongated. FORTRAN callable subprograms for entering the characters into the image were written.

### 4.3 Video Display Monitors

Four colour television receivers were modified to accept the outputs of the video generator, separate red, green and blue video signals and composite sync. Some improvements to their cathode drive circuits were made to allow them to respond to the higher bandwidth video.

The four monitors are identified as 65 cm Körting, 50 cm Körting, 50 cm National and 32 cm National. Appendix A contains their detailed characteristics.

The monitors were all adjusted for optimum raster linearity and colour convergence and purity.

### 4.4 Display Content

As noted in Section 2.1 above, two replications of conventional instruments were chosen for investigation. They were two pointer plus counter air speed indicator and attitude indicator, illustrated in Figures 2*b* and 3*b*. Plates 2, 3, 4 and 5 show them with three other instruments on each of the monitors. It was in these arrangements that they were observed in simulated motion: the airspeed swinging between 200 and 250 knots, and pitch and bank angles between −30 and +30 degrees, using sinusoidal excitation. The actual motion rate was limited, by the speed of the disks in transferring data into the core of the PDP-11/20, at about 8.5 new images (updates) per second: the entire disk being output in approximately 25 seconds.

Plates 6, 7, 8 and 9 illustrate the numeric fonts of Figure 7 displayed on the four monitors.

A tactical display format was devised, and is shown in plates 10 and 11.

## 5. OBSERVATIONS AND MEASUREMENTS

The displays, both static and dynamic, were assessed subjectively and where possible by measurement for factors likely to influence their application to manned flight simulation.

### 5.1 Effects of Pixel Aspects Ratio and Size

The question of the acceptability of the three-by-two aspect ratio pixels generated at the 10 MHz frequency was resolved very rapidly by comparing similar displays produced with 10 MHz and 15 MHz pixel frequencies.

The subjective improvement in display quality of the 15 MHz case over the 10 MHz case was negligible.

With this point settled it was decided to adopt the three-by-two aspect ratio, 10 MHz frequency, pixels in the remainder of the investigations.

Two reasons may be advanced for this result: the first is that, with the exception of the largest monitor, the size of a pixel on the screen is less than the size of a single (red plus green plus blue) phosphor cell on the screen (see below); and the second is that at a viewing distance of 0·75 m the angular subtense of a single pixel ranges downwards from 1·5 mr (for 65 cm Körting, horizontal direction), while the eye can discriminate down to 0·3–0·5 mr under normal room light. Further discussion of the latter point may be found in references [17] and [26].

Pixel and phosphor matrix cell sizes for each of the monitors are given in Table 5.1. Note that for the 65 cm Körting monitor the delta-gun tube gives a hexagonal phosphor cell, and for all the others the cell is rectangular.

**TABLE 5.1**

**Pixel and Phosphor Cell Areas**

| Monitor | Pixel Area | Phosphor Cell Area | Ratio |
|---|---|---|---|
| 65 cm Körting | $0{\cdot}74 \times 10^{-6}\ m^2$ | $0{\cdot}38 \times 10^{-6}\ m^2$ | 1·9 |
| 50 cm Körting | $0{\cdot}43 \times 10^{-6}\ m^2$ | $0{\cdot}72 \times 10^{-6}\ m^2$ | 0·6 |
| 50 cm National | $0{\cdot}43 \times 10^{-6}\ m^2$ | $0{\cdot}62 \times 10^{-6}\ m^2$ | 0·7 |
| 32 cm National | $0{\cdot}18 \times 10^{-6}\ m^2$ | $0{\cdot}41 \times 10^{-6}\ m^2$ | 0·44 |

The ratios, which can be interpreted as the number of phosphor cells per pixel, suggest that resolution should be limited by phosphor cell size on all but the 65 cm Körting monitor. Observations confirmed this at very low display luminance levels. At useful display luminances, spill into adjoining cells caused by beam defocusing or halation reduced the effectiveness of the phosphor cell size control of resolution.

For reference purposes, Table 5.2 contains the horizontal and vertical angular subtenses for pixels and phosphor cells for each of the monitors. Table 5.3 shows the exit-pupil-limited angular sizes and resolutions for the two larger monitors used with Fresnel lenses as collimated displays.

**TABLE 5.2**

**Pixel and Phosphor Cell Subtenses at 0·75 m**

| | Pixel Angular Subtense | | Phosphor Cell Angular Subtense | |
|---|---|---|---|---|
| Monitor | Horizontal | Vertical | Horizontal | Vertical |
| 65 cm Körting | 1·46 mr | 0·90 mr | 1·03 mr | 0·89 mr |
| 50 cm Körting | 1·09 mr | 0·70 mr | 1·10 mr | 1·16 mr |
| 50 cm National | 1·13 mr | 0·68 mr | 1·04 mr | 1·07 mr |
| 32 cm National | 0·70 mr | 0·46 mr | 0·85 mr | 0·85 mr |

Plates 6, 7, 8 and 9, showing the six numeric fonts on each of the monitors, indicate the total resolution effects. Subjectively, all fonts were satisfactory on the 65 cm Körting, the smallest (6 × 3) was marginally useable on both 50 cm monitors and quite useless on the 32 cm National, on which the next font (6 × 4) was also marginal.

## TABLE 5.3

**Angular Sizes under Fresnel Lens Collimation**

| | Lens | Exit-pupil-limited Angular Sizes | | | | | |
|---|---|---|---|---|---|---|---|
| | | Screen | | Pixel | | Phosphor Cell | |
| Monitor | f.l. | Width | Height | Width | Height | Width | Height |
| 65 cm Körting | 0·43 m (17″) | 1·04 r | 0·83 r | 2·5 mr | 1·6 mr | 1·5 mr | 1·5 mr |
| 50 cm Körting | 0·43 m | 0·83 r | 0·65 r | 2·0 mr | 1·2 mr | 1·8 mr | 1·9 mr |
| 65 cm Körting | 0·61 m (24″) | 0·78 r | 0·60 r | 1·8 mr | [illegible] | [illegible] | 1·1 mr |

### 5.2 Flicker

Flicker perception is a complex process in which individual physiological differences and the size, position, luminance, luminance modulation and contrast with background of the flickering object play a part. The key term is the critical fusion frequency (CFF), which is that frequency of brightness change at and above which no brightness change is detected by the human observer. The CFF ranges from over 60 Hz at high light levels on objects subtending large angles at the eye to below 10 Hz for small objects in low light levels. Sherr [17 (p21)] quotes safe (minimum) CFF values as 50 Hz for luminances above about 200 cdm $^{-2}$ and 20 Hz for those below about 20 cdm $^{-2}$.

In the experimental displays, objects consisting of a single pixel or formed from a single raster line flicker at 25 Hz. This was observed to be quite perceptible, under some conditions, early in the investigations. Whilst it is not certain that the existence of perceptible flicker can seriously interfere with an individual's ability to absorb information from a display, it does cause adverse comment and can be unpleasant and lead to claims that it is fatiguing.

It was found, without attempt at particularly accurate measurement but by subjective assessment using many observers, that flicker was not perceptible when the displays' white light luminances were below 100 cd m $^{-2}$, and easily noticed when this quantity much exceeded 200 cd m $^{-2}$. These observations were made at a room horizontal illuminance of approximately 10 lux. (To appreciate 10 lux, note that $10^3$ lux is representative of a cloudy day, $10^{-2}$ lux of a full moonlit night [25].) The 10 lux level was considered to be readily achievable in a research piloted flight simulater, and is adequate for map and other reading.

It was also found to be an advantage to avoid the display of single-pixel or single-line objects.

### 5.3 Aberrations

Aberations in the displayed image are caused by imperfections in the monitors and by limitations of the display technique itself. In the monitors, the factors are raster nonlinearity, colour mis-convergence, and focusing errors. All the display technique limitations are manifestations of picture quantization.

The linearity of each of the monitors was adjusted to the best possible setting, and is plotted in Appendix A. Plate 4, the instruments displayed on the 50 cm National monitor, shows raster non-linearity in the flattening of the bottom dial, at about the worst level encountered. It is at first a little distracting, but becomes less so, possibly as the brain makes compensations as it would for an obliquely viewed object, until it is not noticed.

Another effect of raster linearity arises from the probably inevitable mismatch of the raster scan pattern and that of the phosphor matrix. It is seen, when the screen is filled with a uniform low level illumination, as a random Moiré pattern of typically 15 to 30 mm wavelength. At useful screen luminances the effect disappears, either because of insensitivity of the eye or because of spot dilation at higher beam currents.

In three-gun, shadowmask, colour television tubes convergence is the technique of bringing the "red", "green" and "blue" electron beams together so that they track precisely to produce three coincident rasters of the correct shape [24]. In the case of the delta-gun tubes such as that used in the 65 cm Körting monitor this is a complex procedure involving a dozen or so controls. The in-line and precision-in-line tubes suffer less from convergence errors but provide no adjustment apart from the use of adhesive magnetized tape on the tube envelope.

Mis-convergence can be seen in the top left-hand corner of Plate 10, a tactical display on the 65 cm Körting, and in Plate 11, the same on the 50 cm National. The former had been adjusted to best convergence, the latter being incapable of adjustment. The degree of mis-convergence shown is quite tolerable for domestic television viewing, it is probable that the 65 cm Körting could be improved with component changes.

Mis-convergence of the degree illustrated was subjectively assessed as being fairly insignificant in impact upon the usefulness of the displays. It is, like raster non-linearity, more a distraction that fades with time. It is also always possible to achieve a high quality of convergence in the central area of the monitor screens, and this is where critical image content would be displayed. From the sample so far acquired at ARL it is clear that the variability in achievable convergence among receivers of the same model is considerable, and selection of better performers is advisable.

Focusing limitations were not observed to produce any significant degradation in the quality of the images displayed on any of the monitors.

As noted above, the spatial quantization of the image into pixels is a source of aberrations. The most immediately noticeable effect is the steps and stairs appearance of lines or edges drawn nearly parallel or perpendicular to the raster lines. It is especially pronounced where high contrast edges move slowly. Reduction or subjective elimination of the steps and stairs is not possible with the hardware used. Experiments in which spatial and temporal pseudo-random noise was impressed on the edges did not improve their quality. Once again, it was concluded that this aberration was not serious and could be tolerated with no ill effects.

The "inch-worm" effect can be seen when a short line segment moves in a direction parallel to its length: unless its length is an exact multiple of the pixel dimension it oscillates in length by one pixel as its start and end-points move through the pixel positions, as shown in Figure 8. "Inch-worms" can be suppressed by assembling small objects as fixed pixel patterns and moving them as a whole, as is done with characters and symbols.

A fragmentation of small moving objects, particularly the ends of dial pointers, was observed. It is a result of the lack of synchronism between the display generating mechanism and the raster generator. If necessary, and subjective assessment was that it is not, it can be eliminated by synchronizing the display generator to the frame rate.

### 5.4 Visibility

The visibility measurements described in this section were intended to establish a comparison between the visibility of digits displayed on the monitors and similar-sized characters on an actual aircraft instrument. The observations were made by the author, who has normal colour vision and is experienced in the use of optical instruments.

A threshold contrast visibility measuring instrument, based on a scattering analogue of a graded density filter [23] was used. At the time of these experiments this device had not been calibrated, so that its variable contrast measurement facility could not be used. Rather, it was necessary to set the contrast scale at a suitable value and leave it there, adjusting other parameters to achieve equality of threshold visibility.

A conventional aircraft instrument dial (from a Vertical Speed Indicator) complete with glass and bezel was mounted adjacent to the monitor under test. Both were viewed normally. The numeric fonts, Figure 7, were displayed on the monitor, in white, at a luminance near the subjective maximum useful level. The white colour was subjectively established. Plates 6, 7, 8 and 9 show the displays used.

The contrast scale of the instrument was set to give threshold visibility of the display digits under test at a suitable observation distance. Illumination from incandescent (tungsten) filament lamps was directed upon the dial face, and adjusted by moving the lamps until the characters on the dial were seen at the same threshold visibility.

**Table 5.4: Luminances, Illuminances, and Contrasts of Raster Numeric Fonts and Instrument Dial Characters at Equal Threshold Visibility**

| Display Monitor | Display Font | Display Font Height (mm) | Dial Font Height (mm) | Ambient Illuminance At Display (lux) | Display White Luminance (cd m $^{-2}$) | Display Contrast | Dial Illuminance (lux) | Dial White Luminance (cd m $^{-2}$) | Dial Contrast | Observation Distance (m) |
|---|---|---|---|---|---|---|---|---|---|---|
| 65 cm Körting | 6 · 3 | 6·6 | 3·6 | 9·3 | 213 | 240 | 5500 | 830 | 17 | 2·5 |
| ,, | 6 · 3 | 6·6 | 3·6 | 145 | 221 | 22 | 3000 | 472 | 12 | 2·5 |
| ,, | 7 · 4 | 7·7 | 7·6 | 9·1 | 221 | 270 | 3200 | 518 | 11 | 2·5 |
| ,, | 7 · 4 | 7·7 | 7·6 | 115 | 228 | 27 | 1100 | 134 | 8·8 | 2·5 |
| ,, | 10 · 5 | 11·0 | 7·6 | 9 1 | 199 | 300 | 6500 | 1008 | 14 | 2·5 |
| ,, | 10 · 5 | 11·0 | 7·6 | 73 | 203 | 43 | 3400 | 489 | 14·5 | 2·5 |
| 50 cm Körting | 6 · 3 | 4·9 | 3·6 | 11 | 270 | 245 | 3200 | 495 | 11·5 | 2·25 |
| ,, | 6 · 3 | 4·9 | 3·6 | 84 | 277 | 33 | 1250 | 178 | 9·2 | 2·25 |
| ,, | 7 · 4 | 5·7 | 7·6 | 10·5 | 282 | 300 | 1500 | 295 | 11·8 | 2·25 |
| ,, | 7 · 4 | 5·7 | 7·6 | 83 | 288 | 42 | 785 | 160 | 12·6 | 2·25 |
| ,, | 10 · 5 | 8·2 | 7·6 | 10·5 | 263 | 290 | 3200 | 680 | 11 | 2·25 |
| ,, | 10 · 5 | 8·2 | 7·6 | 82 | 272 | 45 | 2300 | 455 | 11 | 2·25 |
| 50 cm National | 6 · 3 | 5·1 | 3·6 | 9·6 | 248 | 170 | 2700 | 473 | 11 | 2·5 |
| ,, | 6 · 3 | 5·1 | 3·6 | 81 | 255 | 27 | 980 | 167 | 13 | 2·5 |
| ,, | 7 · 4 | 5·9 | 3·6 | 10·1 | 249 | 178 | 3400 | 660 | 14 | 2·5 |
| ,, | 7 · 4 | 5·9 | 3·6 | 74 | 262 | 29 | 2600 | 460 | 11 | 2·5 |
| ,, | 10 · 5 | 8·5 | 7·6 | 9·5 | 238 | 210 | 3700 | 665 | 15 | 2·5 |
| ,, | 10 · 5 | 8·5 | 7·6 | 70 | 247 | 33 | 3000 | 501 | 13 | 2·5 |
| 32 cm National | 6 · 3 | 2·1 | 1·8 | 8·7 | 177 | 210 | 940 | 116 | 3·3 | 1·3 |
| ,, | 6 · 3 | 2·1 | 1·8 | 56 | 182 | 30 | 1260 | 156 | 3·6 | 1·3 |
| ,, | 7 · 4 | 2·4 | 3·6 | 8·9 | 180 | 180 | 790 | 101 | 4·4 | 1·3 |
| ,, | 7 · 4 | 2·4 | 3·6 | 72 | 192 | 25 | 700 | 89 | 4·5 | 1·3 |
| ,, | 10 · 5 | 3·5 | 7·6 | 8·6 | 182 | 200 | 780 | 87 | 11 | 1·3 |
| ,, | 10 · 5 | 3·5 | 7·6 | 78 | 190 | 24 | 570 | 60 | 6 | 1·3 |

A Spectra Pritchard Model 1980 telephotometer was used to make photometric measurements of the photopic luminances of the black and white areas of the display and dial, and of their surface normal illuminances, under the equal threshold visibility conditions. These measurements were made for three of the numeric fonts on each of the four monitors at two ambient illuminances. The results are presented in Table 5.4. Tabulated values of contrast are defined by the relationship

$$c = \frac{L_w - L_b}{L_b}, \text{ where}$$

$c$ is contrast, and $L_w$ and $L_b$ are respectively white and black luminances.

The experimental variable was thus the difference in luminances between screen and dial digits. However it was not possible to alter the illuminance on the dial without changing its contrast because of specular reflection from the paint. Variation in contrast therefore confounds direct comparison of luminances at threshold visibility. The size differences of the display and dial digits, unavoidable to the extent that display digits are constrained to multiples of the various pixel dimensions, further confound the comparisons.

Insofar as allowances can be made for the confounding effects, inspection of the table indicates that there is no overwhelming superiority of display or dial. This holds at least for the displays operated near their subjective maximum useful luminances and the conventional instrument viewed in conditions representative of daylight.

### 5.5 Luminance

Useful display luminances were limited by the onset of flicker in single pixel or single scan line objects, as noted in Section 5.2 above. By keeping the number of such objects to a minimum, screen white area luminances in the range 100 to 200 cd m $^{-2}$ were determined to be acceptable, in an ambient illumination of 10 to 100 lux.

## 6. CONCLUSIONS

The aim of this study was to assess colour raster graphics display methods applied to the presentation of information in the cockpit of a research manned flight simulator. Subjective and objective factors have been investigated.

### 6.1 Subjective Factors

Subjectively, the display method was judged suitable for the application. Aircrew viewing it in the laboratory considered that it was an acceptable alternative to the conventional analogue instruments with which they were familiar. The lack of fine detail of mounting screws and bezels - of makers' names, caused no adverse comment. The simpler presentation, in which only the essentials of the information are displayed was considered by some to be an advantage in the research context.

The intrinsic limitations of the display technique arising from the image quantization, and the residual equipment aberrations in linearity and colour convergence, were recognized to be initial distractions whose impact diminished with familiarity. The use of non-square pixels was found to have no observable effect, and this allows savings of one third in memory capacity and of one address line plus its associated logic.

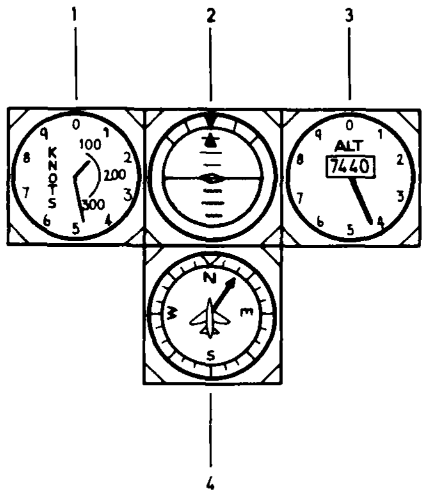
### 6.2 Objective Factors

Measurements of relative visibility of typical raster displays and an actual aircraft instrument were made. These confirmed the subjective impression that the displays exhibited adequate visibility characteristics. It was found that the displays, operated under suitable conditions, present comparable visibility with the aircraft instruments in daylight use. These conditions

were determined to be adequate for the other cockpit activities, such as reading or writing, expected to be needed in manned flight simulation research. The conditions could be achieved in a simulator.

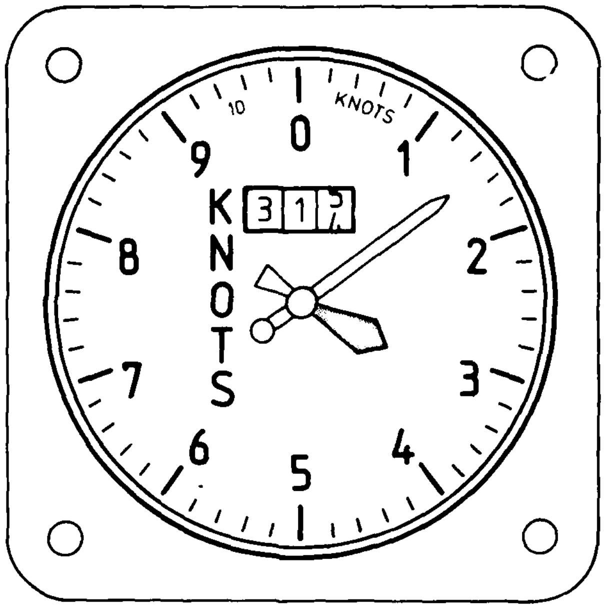
### 6.3 Summary

Computer driven colour raster graphic displays utilizing modified television receiver monitors have been shown to be capable of solving the problem of cockpit information presentation in manned flight simulation research. The method offers a unified approach for both conventional and integrated cockpit designs, with total versatility resulting from programmability. Hardware cost estimates predict an order-of-magnitude reduction in the cost of cockpit information presentation by this method in comparison to the conventional approach.

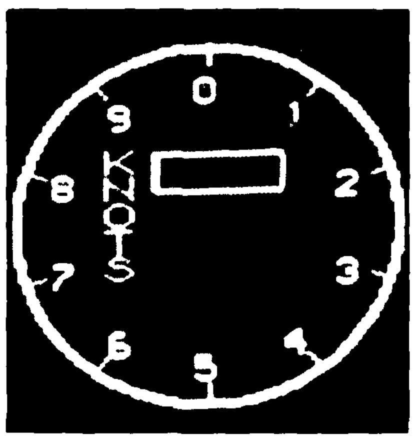



Legend
1. Air speed indicator
2. Attitude indicator
3. Altimeter
4. Horizontal situation indicator

FIG. 1 THE "BASIC T" OF CONVENTIONAL INSTRUMENTS

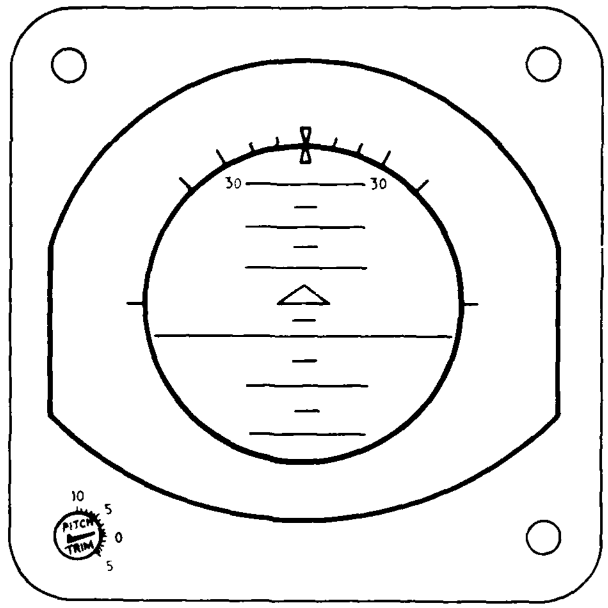



(a) Sketch of actual instrument

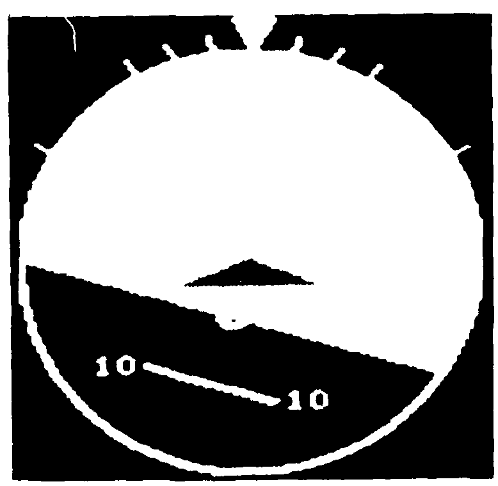



(b) Raster graphics representation

FIG. 2 TWO POINTER PLUS COUNTER AIR SPEED INDICATOR




(a) Sketch of actual instrument




(b) Raster graphics representation

FIG. 3 ATTITUDE INDICATOR

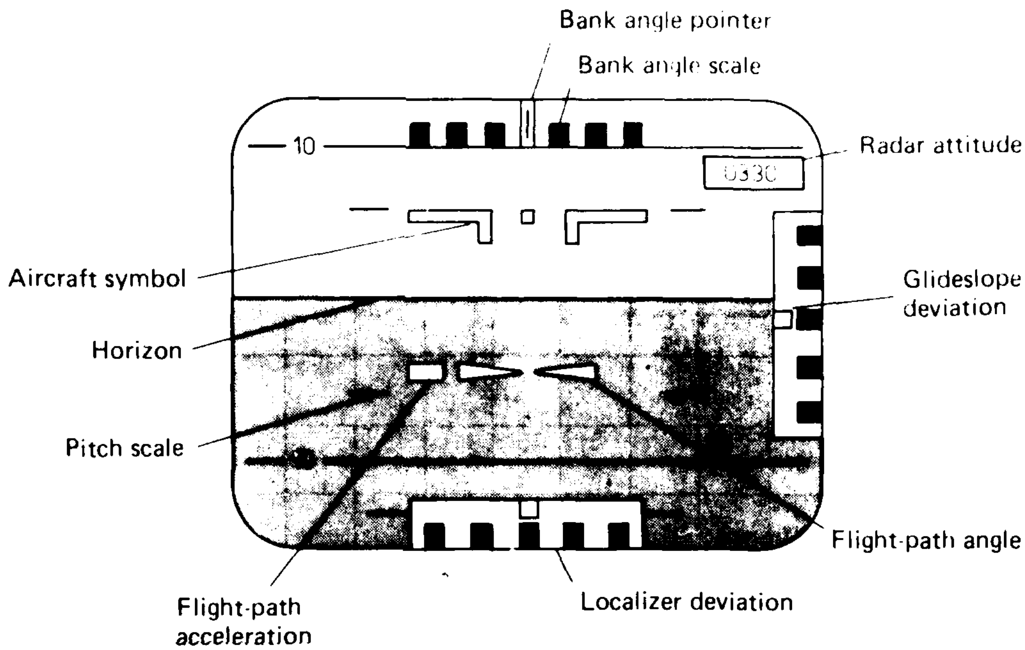



FIG. 4 NASA EADI BASIC FORMAT

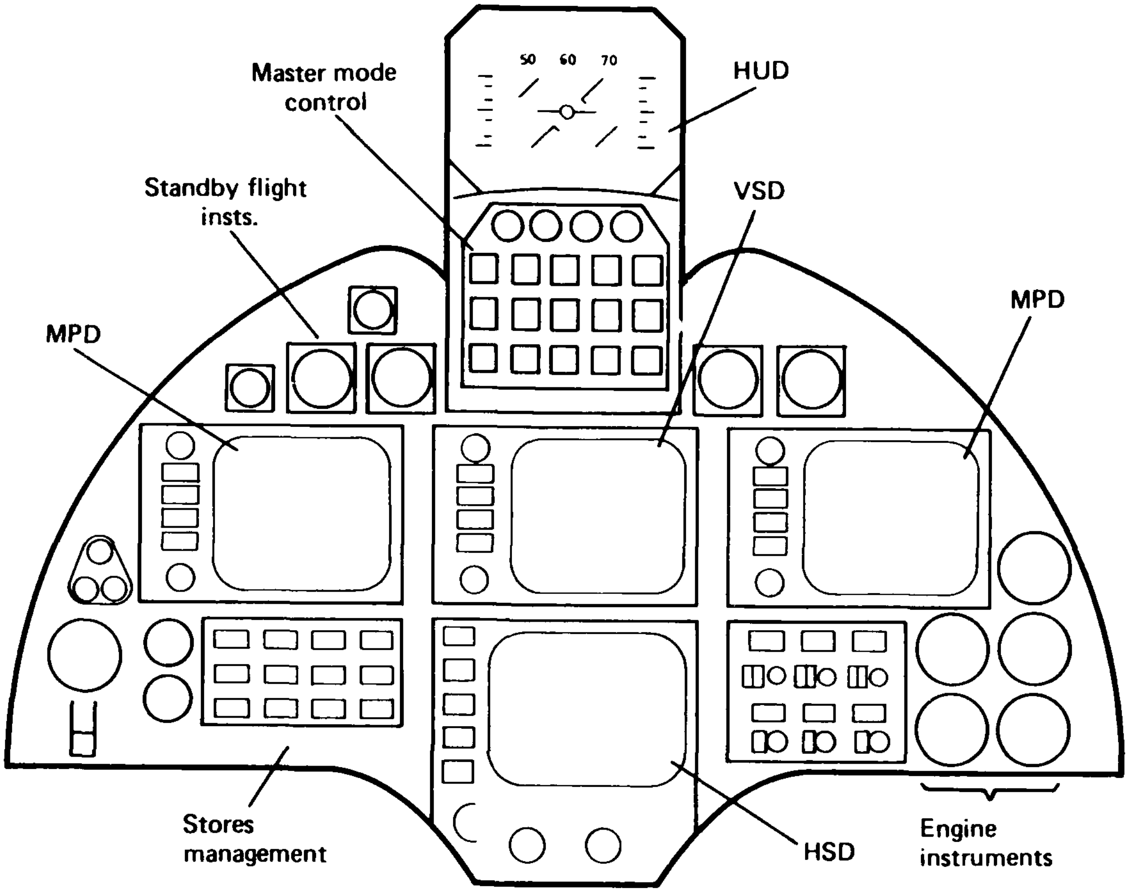



FIG. 5 TYPICAL DAIS COCKPIT INSTRUMENT PANEL LAYOUT. [13].

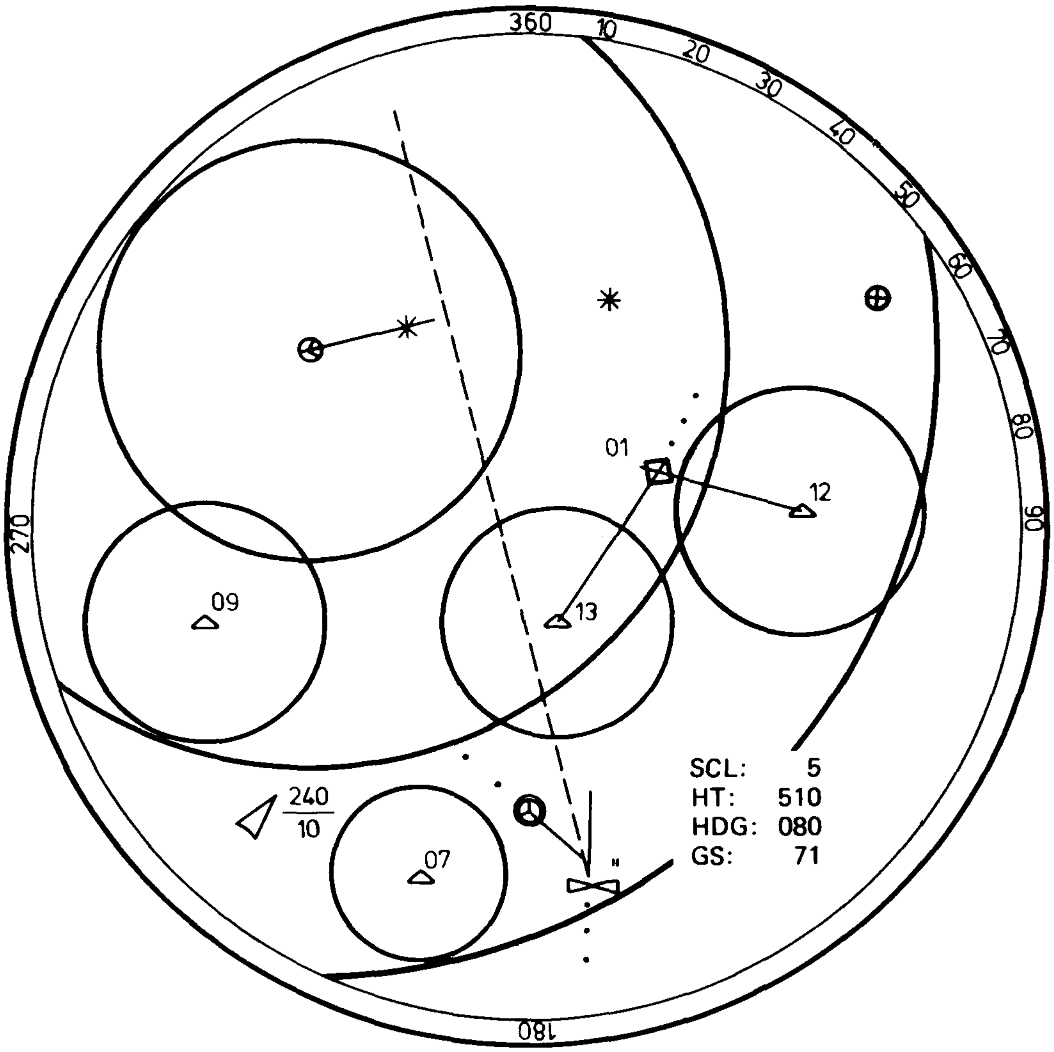



FIG. 6 AIRBORNE ASW TACTICAL DISPLAY FORMAT

FONT SIZE: 6X3 0123456789

FONT SIZE: 6X4 0 1 2 3 4 5 6 7 8 9

FONT SIZE: 7X4 0 1 2 3 4 5 6 7 8 9

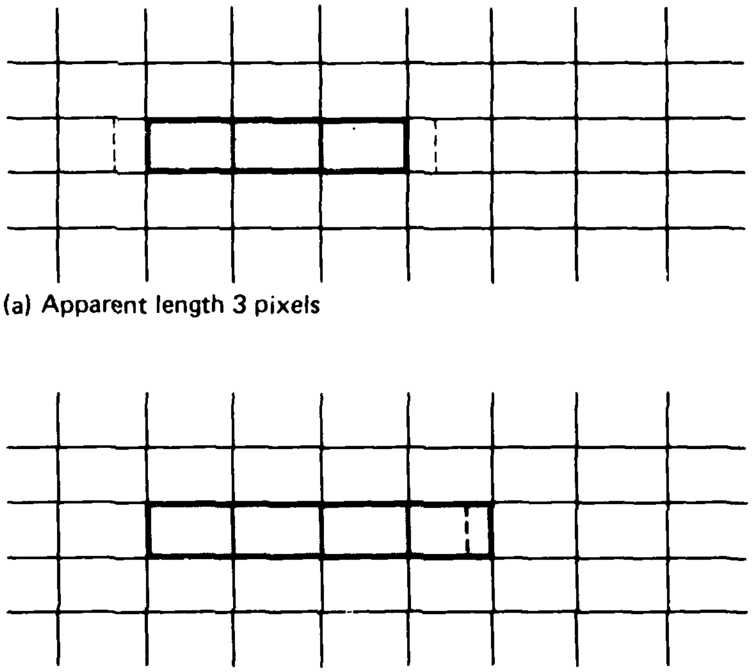
FONT SIZE: 8X4 0 1 2 3 4 5 6 7 8 9

FONT SIZE: 9X5 0 1 2 3 4 5 6 7 8 9

FONT SIZE: 1ØX5 0 1 2 3 4 5 6 7 8 9

FIG. 7 PIXEL ARRANGEMENTS IN NUMERIC FONTS

Display of line of true length $3^{2}/3$ pixels



(a) Apparent length 3 pixels

(b) Apparent length 4 pixels

FIG. 8 "INCH-WORM" ABERRATION.

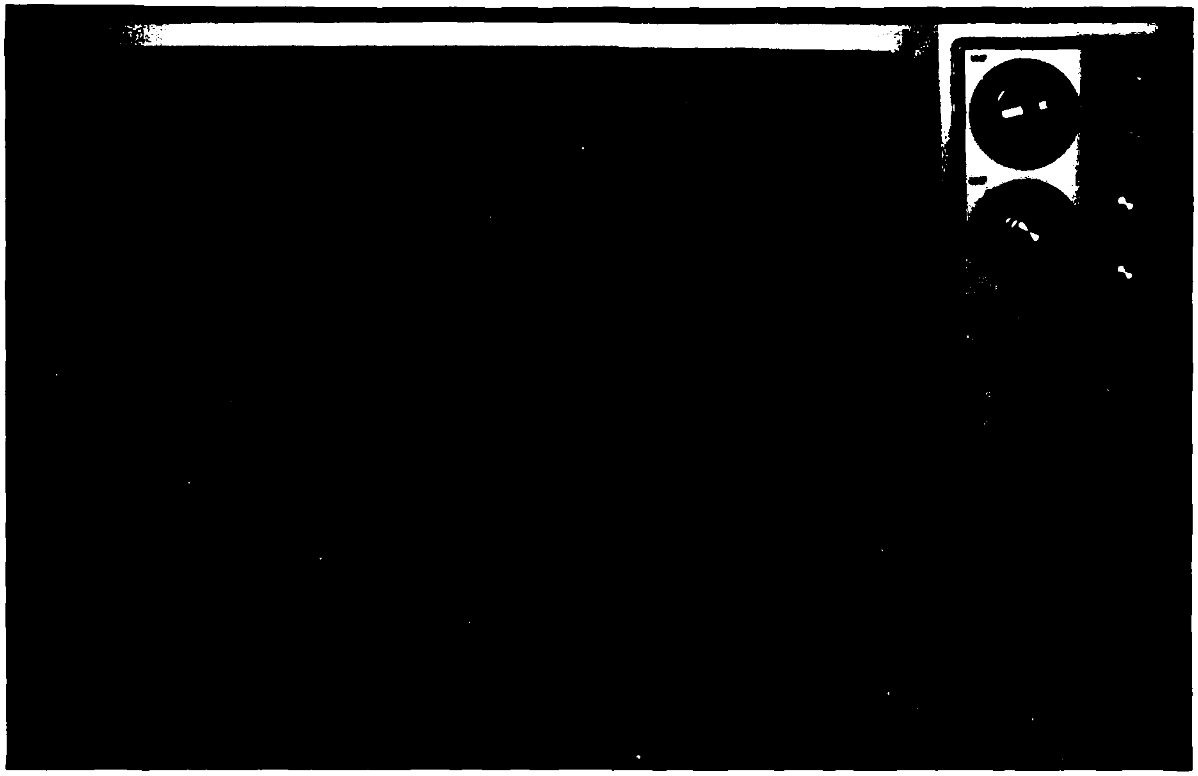


PLATE 1: 50CM NATIONAL RECEIVER WITH AIRCRAFT INSTRUMENTS

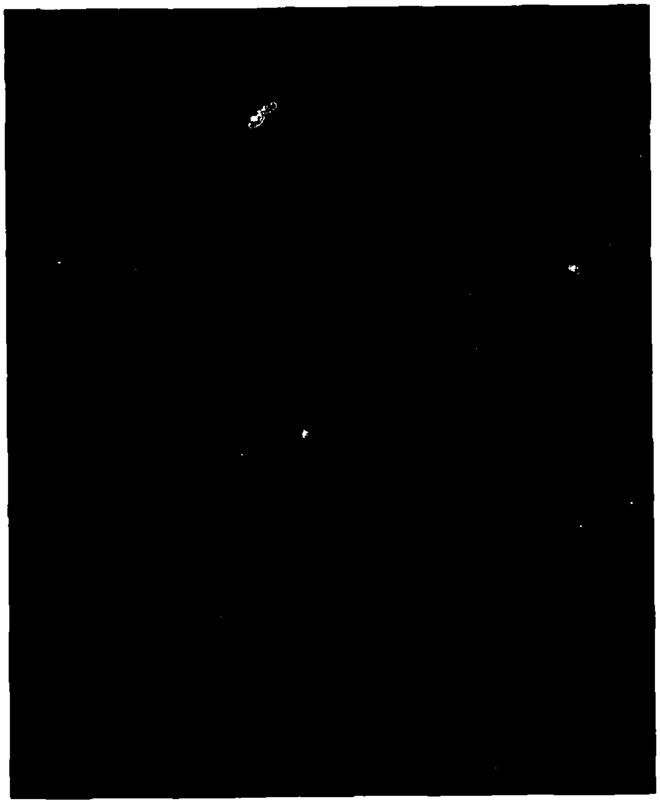


PLATE 2: AIRCRAFT INSTRUMENTS ON 65CM KORTING

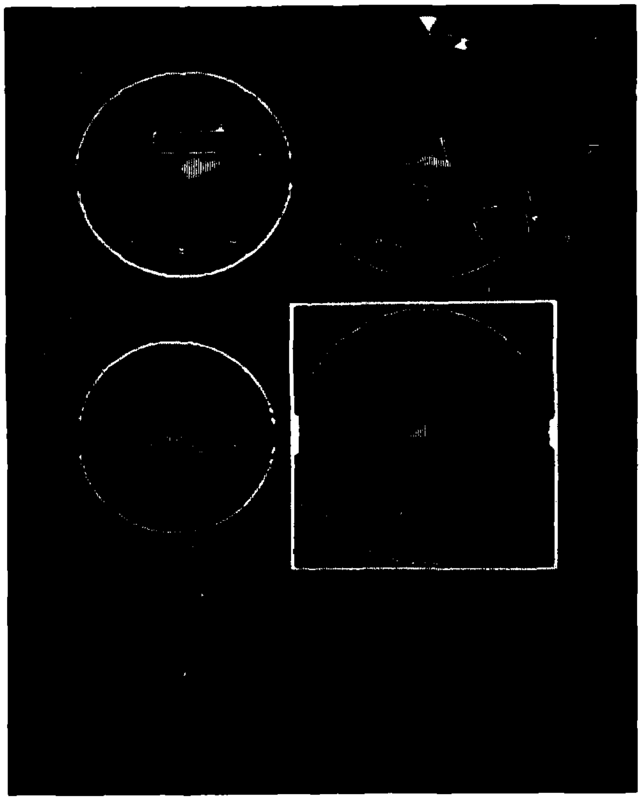


PLATE 3: AIRCRAFT INSTRUMENTS ON 50CM KORTING

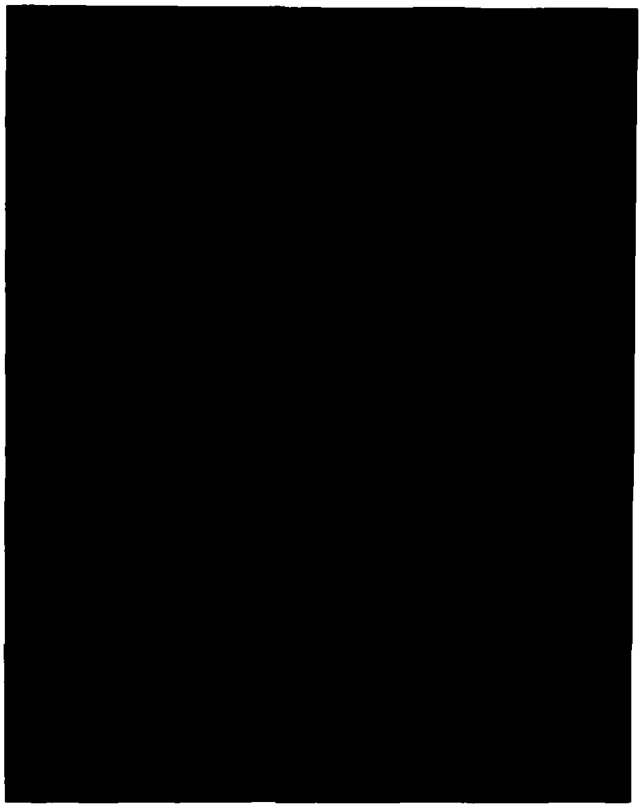


PLATE 4: AIRCRAFT INSTRUMENTS ON 50CM NATIONAL

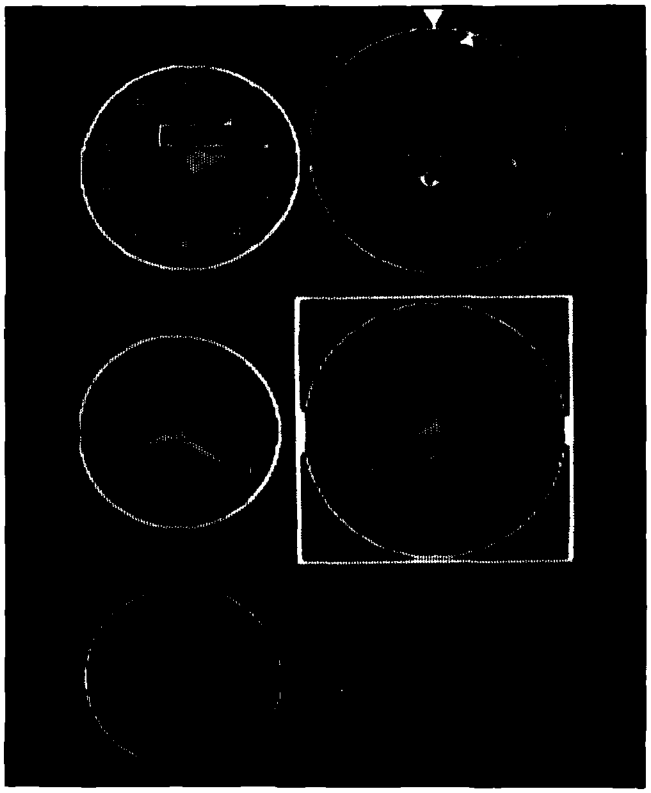


PLATE 5: AIRCRAFT INSTRUMENTS ON 32CM NATIONAL

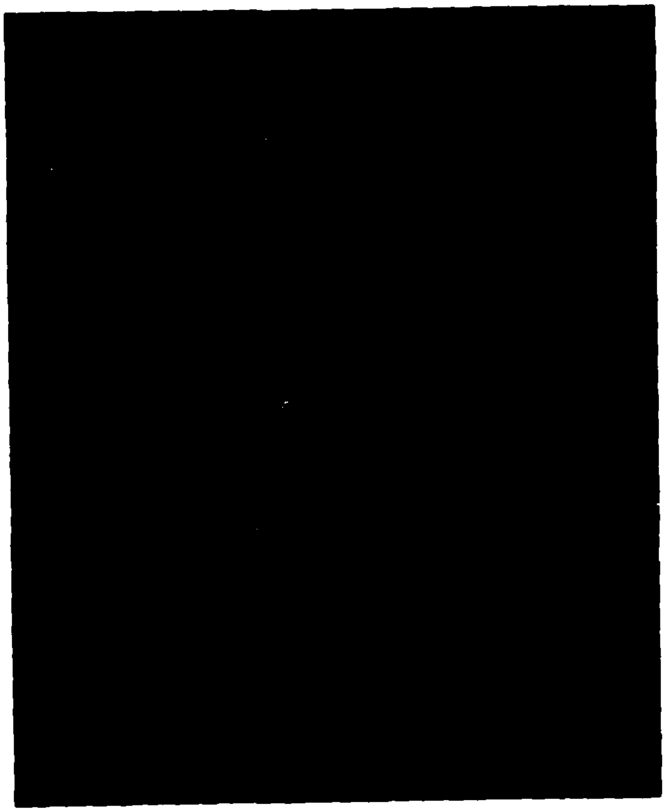


PLATE 6: NUMERIC FONTS ON 65CM KORTING

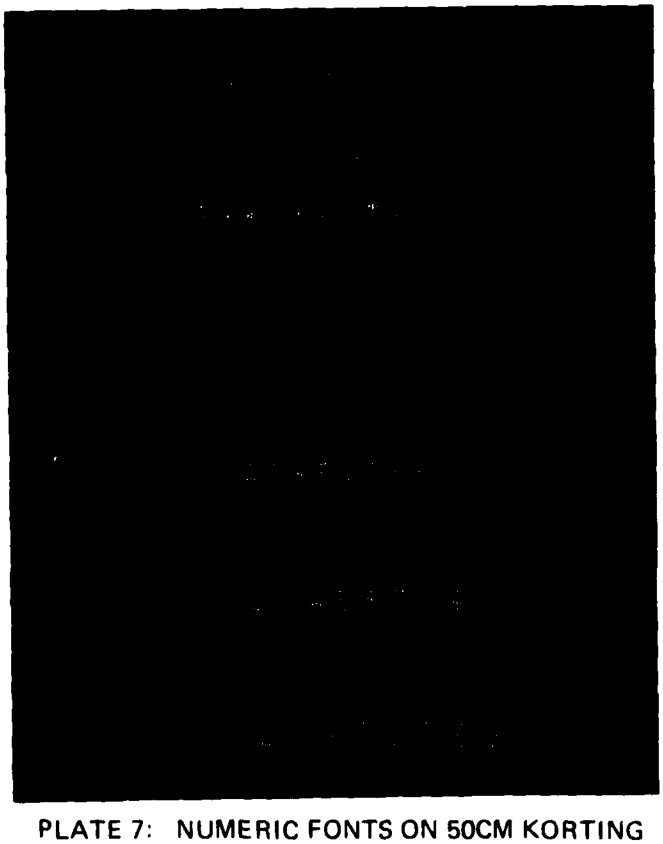


PLATE 7: NUMERIC FONTS ON 50CM KORTING

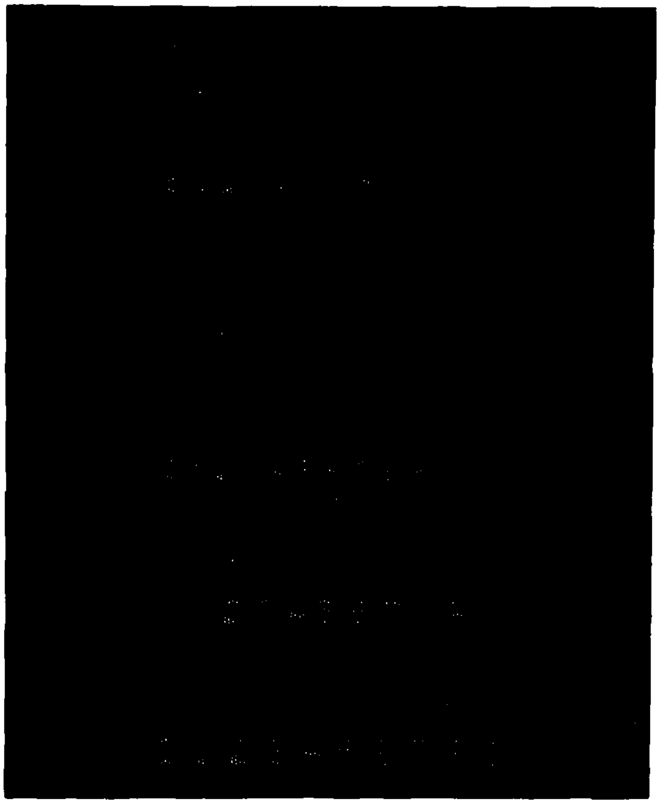


PLATE 8: NUMERIC FONTS ON 50CM NATIONAL

PLATE 9: NUMERIC FONTS ON 32CM NATIONAL

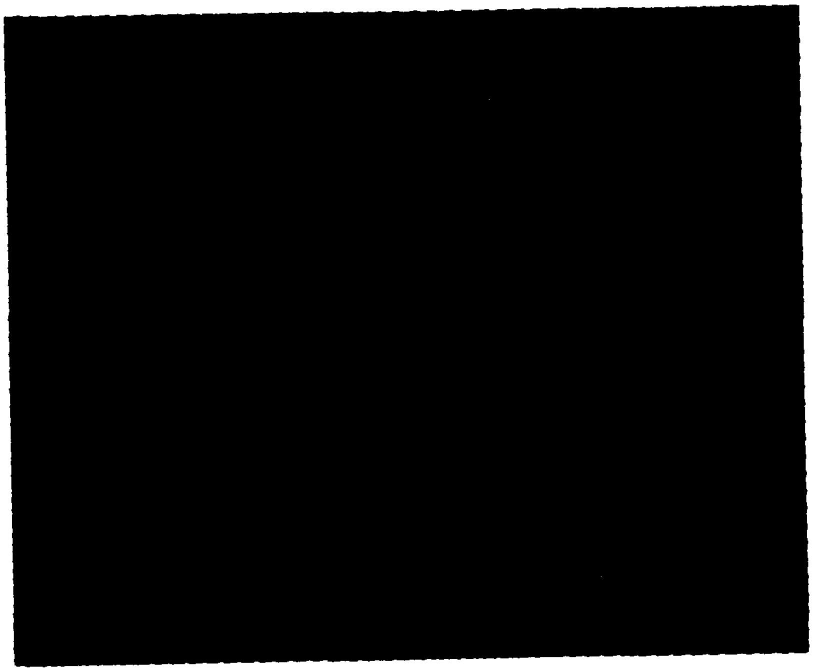


PLATE 10: TACTICAL DISPLAY ON 65CM KORTING (showing mis-convergence in *upper left corner)*

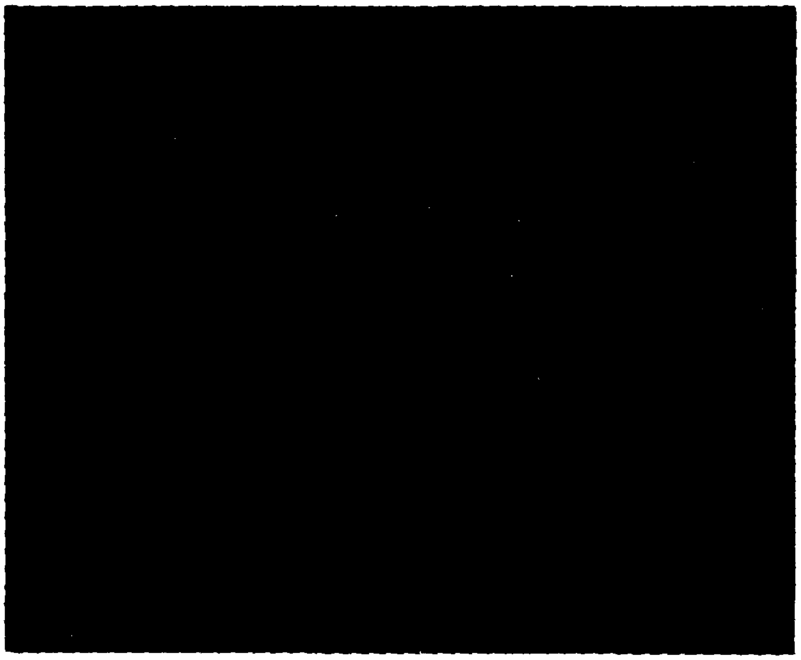


PLATE 11: TACTICAL DISPLAY ON 50CM NATIONAL (showing slight mis-convergence on left hand side)

## REFERENCES


[1] Lovesey, E. J., "The development of aircraft instruments", in AGARD Conference Proceedings No. 201, "Visual presentation of cockpit information including special devices used for particular conditions of flying", G. Perdriel, Ed., NATO (AGARD), November 1976, ISBN 92-835-0181-0.

[2] Zipoy, D. R., Premselaar, S. J., and Kopchick, N. A., "Advanced Integrated fighter cockpit study", USAF Air Force Flight Dynamics Laboratory Technical Report AFFDL-TR-71-57, May 1974.

[3] – "Advanced Integrated Modular Instrumentation System (AIMIS)", Naval Air Development Centre, in Proceedings, Second Advanced Aircrew Display Symposium, Naval Air Test Center, 23–24 April 1975.

[4] "Evolution of the Instrument Panel", (two parts) Smiths Industries Aviation Review Vols 32, 34, 1976.

[5] Rolfe, J. M., "The Fighter Cockpit *1910–1963*", Royal Air Force *Institute of Aviation* Medicine, Report No. 222, 1964.

[6] "Dimensions of Instrument Cases (Aircraft)", Australian Defence Standard, DEF (AUST)-300B.

[7] "Principles of Presentation of Information in Aircraft", Australian Defence Standard, DEF (AUST)-392.

[8] — "Numerals and Letters for Aircrew Station Displays", Australian Defence Standard, DEF (AUST)-293.

[9] — Report of the 17th Meeting, Working Party 10, Air Standardization Coordinating Committee, London, September 1975.

[10] Hearne, P. A., "Trends in Technology in Airborne Electronic Displays", in AGARD Conference Proceedings No. 167, "Electronic Airborne Displays", J. Leysieffer, Ed., NATO (AGARD), December 1975.

[11] Steinmetz, G. G., Morello, S. A., Knox, C. E., and Person, L. H. Jr., "A Piloted-Simulation Evaluation of Two Electronic Display Formats for Approach and Landing", NASA TN D-8183, 1976.

[12] Morello, S. A., Knox, C. E., and Steinmetz, G. G., "Flight-Test Evaluation of Two *Electronic Display Formats for Approach to Landing* Under Instrument Conditions", NASA Technical Paper 1085, 1977.

[13] Kopchick, N. A., and Premselaar, S. J., "The DAIS Design and System Integration Aspects of Electronic Airborne Controls and Displays", in AGARD Conference Proceedings No. 167, "Electronic Airborne Displays", J. Leysieffer, Ed., NATO (AGARD), December 1975.

[14] Adam, E. C., "F-18 Crew Station Design-Update", in Proceedings, Third Advanced Aircrew Display Symposium, Naval Air Test Center, 19–20 May 1976.

[15] Hendy, K. C., and Anderson, K. W., "Sea King Update: A Human Engineering Study", Systems Report *13*, ARL, *1979*.

[16] "Technical Standards for the Australian Television Service", Australian Broadcasting Control Board, 5th Edition, December 1976.

[17] Sherr, S., "Fundamentals of Display System Design", Wiley-Interscience, N.Y., 1970.

[18] Czuchry, A. J., Engel, H. E., Dowd, R., Baran, H. A., and Greene, R., "Mid-1980s Digital Avionics Information System Conceptual Design Configuration", U.S.A.F. Air Force Human Resources Laboratory Technical Report AFHRL-TR-76-59, July 1976.

[19] Slocum, G. K., "Display Devices and their Use in Avionics Systems", in AGARD Lecture Series No. 71, "Opto-Electronics", Stringer, F. S., Ed., NATO (AGARD), September 1974.

[20] Hearne, P. A., and Hussey, D. W., "Some Engineering and Operational Factors of Multi Sensor Displays", in AGARD Conference Proceedings No. 96, "Guidance and Control Displays", NATO (AGARD), October 1971.

[21] Ross, W. T., "T.V. Sync. and Grid Pattern Generator", A.R.L. Flight Systems Group Memorandum FSG 42, February 1977.

[22] Warne, D. K., "Command and Information System 1 Programming and Operation Manual", A.R.L. System Factors Group Memorandum SFG 31, 1974, revised by T. Kinsella, December 1975.

[23] Clark, B. A., A.R.L., Personal Communication.

[24] Hutson, G. H., "Colour Television Theory", McGraw Hill, 1971.

[25] Mann, G., "Performance Requirements for Airborne Multifunction Display Systems", in AGARD Conference Proceedings No. 167, "Electronic Airborne Displays", T. Leysieffer, Ed., NATO (AGARD), December 1975.

[26] Luxenberg, H. R., and Kuehn, R. L., "Display Systems Engineering", McGraw-Hill, 1968.

## APPENDIX A

### Television Receivers Characteristics

1. "65 cm Körting".

   (a) Make: Körting Radio Werke G.M.B.H., Grassau, W. Germany.

   (b) Model: Körting-Transmare Videocolor 5513, Type 56 791.

   (c) Picture Tube: Delta-gun.

   (d) Screen Size: 650 mm (27 inch) nominal diagonal. Dimensions measured over anti-implosion screen to limits of phosphor:

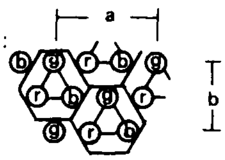
   | | |
   |---|---|
   | Diagonal: | 639 mm |
   | Width at centre: | 534 mm |
   | Height at centre: | 363 mm |

   (e) Raster Size: (10 MHz pixel rate, 512 lines of 512 pixels).

   (i) Horizontal: 561 mm (estimated—raster exceeds screen width).

   (ii) Vertical: 347 mm.

   (f) Phosphor Matrix:




   | | a | b |
   |---|---|---|
   | centre of screen | 1·147 | 0·666 |
   | limit of screen | 1·114 | 0·651 |

   From (e)(ii), each line occupies 347/512 ≈ 0·67 mm, comparable with dimension "b", the minimum diameter of the tessellating hexagons.

   (g) Linearity: See diagram.

   (h) Average Screen Reflectivity: 0·24

2. "50 cm Körting".

   (a) Make: Körting Radio Werke G.M.B.H., Grassau, W. Germany.

   (b) Model: Körting-Transmare Videocolor 5507, Type 56 665.

   (c) Picture Tube: Precision In-line.

   (d) Screen Size: 500 mm (20 inch) nominal diagonal. Dimensions measured over anti-implosion screen to limits of phosphor:

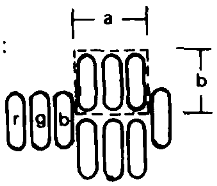
   | | |
   |---|---|
   | Diagonal: | 491 mm |
   | Width at centre: | 412 mm |
   | Height at centre: | 306 mm |

   (e) Raster Size: (10 MHz pixel rate, 512 lines of 512 pixels).

   (i) Horizontal: 418 mm (estimated—raster exceeds screen width).

   (ii) Vertical: 270 mm.

(f) Phosphor Matrix:




| | a | b |
|---|---|---|
| centre of screen | 0·825 | 0·873 |
| limit of screen | 0·836 | 0·869 |

From (e) (ii), each line occupies 270/512 ≈ 0·53 mm, while pixel width is 418/512 ≈ 0·82 mm.

(g) Linearity: See diagram.

(h) Average Screen Reflectivity: 0·28.

3. "50 cm National".

(a) Make: "National"— Matsushita Electric Trading Co. Ltd., Osaka, Japan.

(b) Model: TC-2002.

(c) Picture Tube: 48 cm, 90° Deflection, In Line.

(d) Screen Size: 480 mm (19 inch) nominal diagonal. Dimensions measured over anti-implosion screen to bezel:

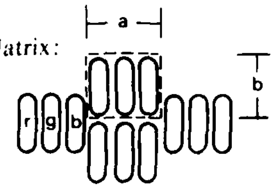
| | |
|---|---|
| Diagonal: | 480 mm |
| Width at centre: | 402 mm |
| Height at centre: | 298 mm |

(e) Raster Size: (10 MHz pixel rate, 512 lines of 512 pixels).

(i) Horizontal: 434 mm (estimated – raster exceeds screen width).

(ii) Vertical: 263 mm.

(f) Phosphor Matrix:




| | a | b |
|---|---|---|
| centre of screen | 0·778 | 0·801 |
| limit of screen | 0·782 | 0·801 |

From (e) (ii), each raster line occupies 263/512 ≈ 0·51 mm, pixel width is 434/512 ≈ 0·85 mm.

(g) Linearity: See diagram.

(h) Average Screen Reflectivity: 0·41.

4. "32 cm National".

(a) Make: "National"– Matsushita Electric Trading Co. Ltd., Osaka, Japan.

(b) Model: TC-1301.

(c) Picture Tube: 32 cm, 90° Deflection, Quintrix (In line).

(d) Screen Size: 320 mm (13 inch) nominal diagonal. Dimensions measured over anti-implosion screen to bezel:

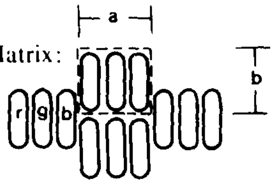
| | |
|---|---|
| Diagonal: | 297 mm |
| Width at centre: | 256 mm |
| Height at centre | 199 mm |

(e) Raster Size: (10 MHz pixel rate, 512 lines of 512 pixels).

(i) Horizontal: 270 mm (estimated  raster exceeds screen size).

(ii) Vertical: 177 mm.

(f) Phosphor Matrix:



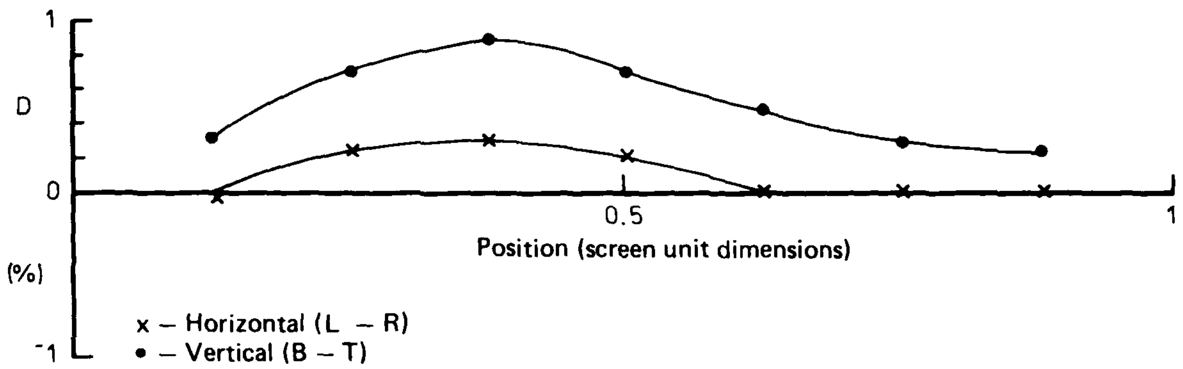

| | a | b |
|---|---|---|
| centre of screen | 0·641 | 0·639 |
| limit of screen | 0·613 | 0·614 |

From (e) (ii) each raster line occupies 177/512 $\approx$ 0·35 mm; pixel width is 270/512 $\approx$ 0·53 mm.

(g) Linearity: See diagram.

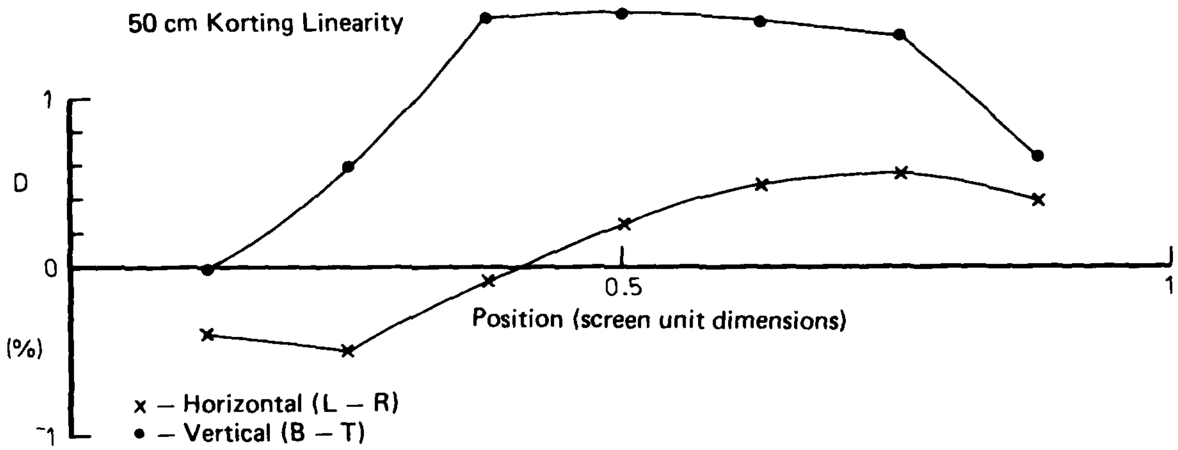
(h) Average Screen Reflectivity: 0·33.

65 cm Korting linearity




PLOT OF LINEARITY DEVIATION AS A PERCENTAGE OF FULL SIZE

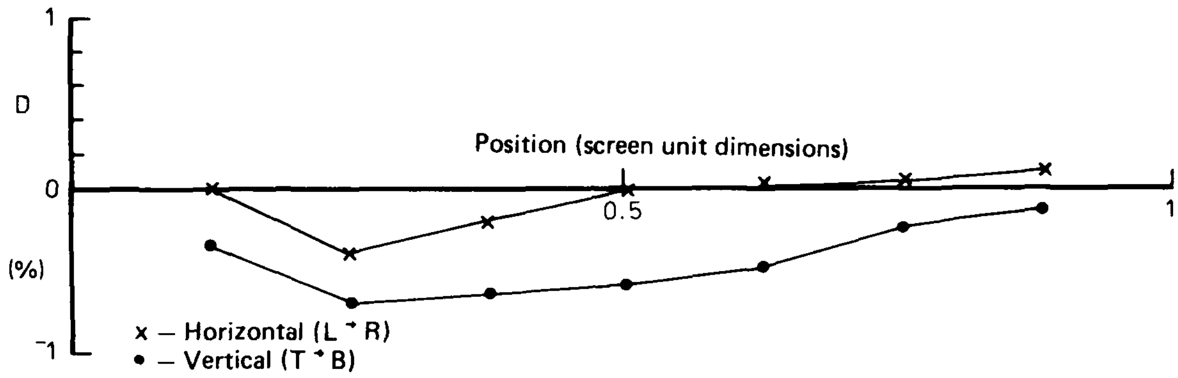
50 cm Korting Linearity




PLOT OF LINEARITY DEVIATION AS A PERCENTAGE OF FULL SIZE

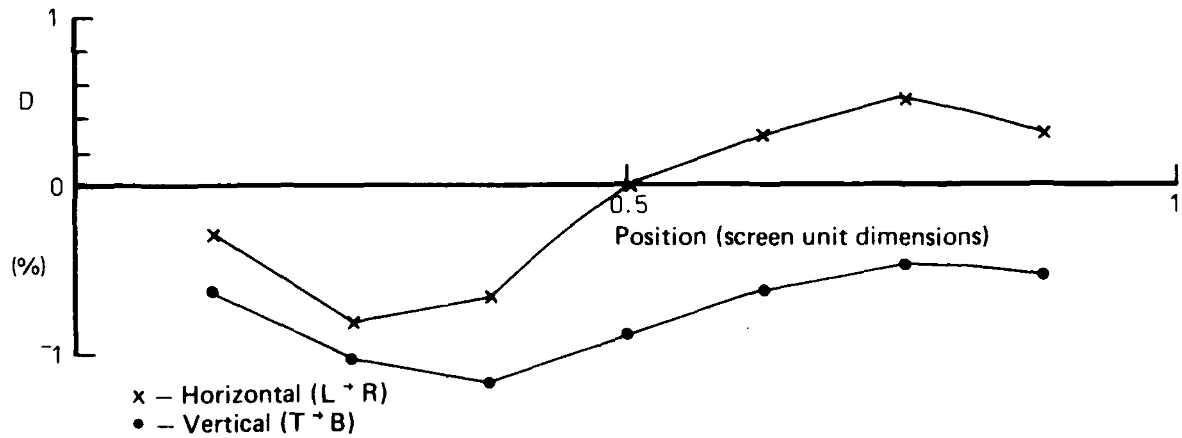
APPENDIX A

50 cm Korting linearity




PLOT OF LINEARITY DEVIATION AS A PERCENTAGE OF FULL SIZE

32 cm National linearity




PLOT OF LINEARITY DEVIATION AS A PERCENTAGE OF FULL SIZE

## DISTRIBUTION

| | Copy No. |
|---|---|
| **AUSTRALIA** | |
| **Department of Defence** | |
| **Central Office** | |
| Chief Defence Scientist | 1 |
| Deputy Chief Defence Scientist | 2 |
| Superintendent, Science and Technology Programs | 3 |
| Australian Defence Scientific and Technical Representative (UK) | — |
| Counsellor, Defence Science (USA) | — |
| Joint Intelligence Organisation | 4 |
| Defence Library | 5 |
| Document Exchange Centre, D.I.S.B. | 6–22 |
| **Aeronautical Research Laboratories** | |
| Chief Superintendent | 23 |
| Library | 24 |
| Superintendent – Systems Division | 25 |
| Divisional File – Systems | 26 |
| Author: H. A. Thelander | 27 |
| **Materials Research Laboratories** | |
| Library | 28 |
| **Defence Research Centre, Salisbury** | |
| Library | 29 |
| **Central Studies Establishment** | |
| Information Centre | 30 |
| **Engineering Development Establishment** | |
| Library | 31 |
| **RAN Research Laboratory** | |
| Library | 32 |
| **Navy Office** | |
| Naval Scientific Adviser | 33 |
| **Army Office** | |
| Army Scientific Adviser | 34 |
| Royal Military College Library | 35 |
| **Air Force Office** | |
| Aircraft Research and Development Unit, Scientific Flight Group | 36 |
| Air Force Scientific Adviser | 37 |
| RAAF Academy, Point Cook | 38 |
| **Department of Productivity** | |
| **Government Aircraft Factories** | |
| Manager Library | 39 |
| **Department of Transport** | |
| Library | 40 |

**Statutory, State Authorities and Industry**

| | | |
|---|---|---|
| Australian Atomic Energy Commission, Director | | 41 |
| CSIRO, Division of Computing Research | | 42 |
| Qantas, Library | | 43 |
| Qantas, R. L. Page, Simulator Division | | 44 |
| Trans Australia Airlines, Library | | 45 |
| Ansett Airlines of Australia, Library | | 46 |
| Commonwealth Aircraft Corporation: Manager of Engineering | | 47 |
| Hawker de Havilland Pty Ltd: Librarian, Bankstown | | 48 |

**Universities and Colleges**

| | | |
|---|---|---|
| Adelaide | Barr Smith Library | 49 |
| Flinders | Library | 50 |
| James Cook | Library | 51 |
| LaTrobe | Library | 52 |
| Melbourne | Engineering Library | 53 |
| Monash | Library | 54 |
| Newcastle | Library | 55 |
| New England | Library | 56 |
| Sydney | Engineering Library | 57 |
| Queensland | Library | 58 |
| Tasmania | Engineering Library | 59 |
| Western Australia | Library | 60 |
| R.M.I.T. | Library | 61 |

**CANADA**

| | |
|---|---|
| International Civil Aviation Organization, Library | 62 |
| NRC, National Aeronautical Establishment, Library | 63 |
| NRC, Division of Mechanical Engineering, Director | 64 |

**FRANCE**

| | |
|---|---|
| AGARD, Library | 65 |
| ONERA, Library | 66 |
| Service de Documentation, Technique de l'Aeronautique | 67 |

**GERMANY**

| | |
|---|---|
| ZLDI | 68 |

**INDIA**

| | |
|---|---|
| National Aeronautical Laboratory, Director | 69 |

**ITALY**

| | |
|---|---|
| Associazione Italiana di Aeronautica e Astronautica | 70 |

**JAPAN**

| | |
|---|---|
| National Aerospace Laboratory, Library | 71 |

**Universities**

| | | |
|---|---|---|
| Tokyo | Inst. of Space and Aeroscience | 72 |

**NETHERLANDS**

| | |
|---|---|
| National Aerospace Laboratory (NLR), Library | 73 |

**NEW ZEALAND**

| | |
|---|---|
| Librarian, Defence Scientific Establishment | 74 |
| Transport Ministry, Civil Aviation Division, Library | 75 |

| | |
|---|---|
| **SWEDEN** | |
| Aeronautical Research Institute | 76 |
| SAAB-Scania, Library | 77 |
| Research Institute of the Swedish National Defence | 78 |
| **SWITZERLAND** | |
| Institute of Aerodynamics, Professor J. Ackeret | 79 |
| **UNITED KINGDOM** | |
| Aeronautical Research Council, Secretary | 80 |
| C.A.A.R.C., Secretary | 81 |
| Royal Aircraft Establishment: | |
| Farnborough, Library | 82 |
| Bedford, Library | 83 |
| National Physical Laboratories, Library | 84 |
| **Universities and Colleges** | |
| Cranfield Institute of Technology, Library | 85 |
| **UNITED STATES OF AMERICA** | |
| NASA Scientific and Technical Information Facility | 86 |
| American Institute of Aeronautics and Astronautics | 87 |
| Battelle Memorial Institute, Library | 88 |
| Naval Air Test Center | 89 |
| Air Force Human Resources Lab. | 90 |
| Air Force Avionics Lab. | 91 |
| Air Force Flight Dynamics Lab. | 92 |
| Spares | 93-102 |

ATE
LMED
-8